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EXPERIMENTAL INVESTIGATION OF THE CONTRIBUTION OF RESONANT FREQUENCY TO TRUMPETER'S PERFORMANCE

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Previous work by the authors explored the bodily posture of trumpet players, its effect on performance, and how it might be improved. This project sharpens the focuses to look primarily at the sound output of the trumpet player. The quality of the sound produced by a trumpeter is the result of the combination of the instrument acoustic properties with the performing techniques of the player. Specifically, we investigate the resonant frequencies as they provide a good indication of timbre stability.

Focusing on the way that the vocal tract, as the airstream source, is modified by the trumpeter, the tone quality of the trumpet performance is examined by means of comparisons of spectral analysis. For this purpose, and in order to limit the various parameters that can affect the acoustic properties of the instrument, one performer has been recorded playing musical excerpts, scales and arpeggios with the same instrument. The experiment is then expanded by including different trumpet mouthpieces played by the same participant.

In this paper, we present the differences in the spectral energy observed for these case studies, and suggest how the results obtained from the statistical analyses of the observed resonant frequencies will contribute to the design of an experimental software application aiming to help performers improving their tone quality.

1. Introduction: Acoustic principles of the trumpet

Trumpet pedagogy relates to the teaching and study of techniques for all levels of trumpet players. It has historically focussed on musical output (rather than tone explicitly). Moreover, tutorial materials typically provide numerous exercises to be performed, but offer little guidance on their technical and physical aspects [1, 2, 3]. A smaller amount of mostly relatively recent literature has focussed on the role of the body [4, 5, 6], including earlier work by two of the authors [7, 8].

The way in which the trumpet produces sound is surprisingly complex. For an instrument that is, to most people, exceedingly familiar, the nuances of its sound production remain little studied and poorly understood. Its sound output is a combination of various interrelated elements, all of which affect the resultant resonant frequencies. The performer's lips can be considered the sound source creating a periodic pressure wave and exciting the air resonating at the natural frequency of the trumpet's air tube. The lips play the role of a "double reed" (lip reeds) and they "close" the input end of the trumpet. The combination of a lengthy conical tube and an open bell cause the trumpet to behave like a closed-end tube. Thus, in addition to the fundamental frequency, odd as well as even harmonics are produced [9]. Various studies have investigated the acoustic behaviour of the different parts of the instrument but the complexity of this behavior has yet to be fully outlined. The impedance of the instrument has been studied with the use of piezo-transducer onto the mouthpiece of the instrument in an attempt to remove the variable aspects of lip performance or individual performing techniques [10].

The literature of brass techniques has also focused on the importance of the posture of the trumpet player. Posture has been extensively discussed for the performance of all musical instrument, but it is an important parameter for wind instruments, where the body of the performer can be considered as a continuation of the trumpet system, beginning with controlling the pressurised air from the lungs to the vocal tract, the tongue and the lips, and to the instrument tube and bell [10, 11]. The position of the tongue can also change the pitch of a wind instrument. Studies [12, 13] have measured its effects in the mouth of players miming or actually performing the clarinet and the didjeridu, respectively.

Previous studies have suggested that the vocal tract can also influence wind instruments. Clear involvement of the vocal tract in pitch from reed wound wind instruments has been shown. The acoustic pressure in the mouth of clarinetists [14, 15] and saxophonists [16, 17] has been measured with a microphone in the mouths of performers while they were playing. Using the same method, Chen [18] has shown, however, that there is no consistent vocal tract tuning by the trumpet players.

For the current study, we performed an acoustic analysis of the recorded sound by using the voice analysis program Praat. Praat is commonly used for the analysis of speech and singing sounds, and provides information about the singing formants. Formants are the acoustic resonances of the vocal tract, produced by modifying the spaces between the larynx, pharynx, oral and nasal cavity. The analysis of the sounds includes the entire system of performer and trumpet. Thus, “formants” analysed by the Praat software should not be considered to be the resonant frequencies of the vocal tract alone, but the resonant frequencies of the entire system. This will also include any resonances caused by the tongue, lips, and the trumpet itself.

2. Case study

2.1 Performing a musical excerpt

For the purpose of this study, a professional trumpet player was recorded in a professional studio, playing a Bb Yamaha Xeno Trumpet with a Yamaha TR-16C4-GP mouthpiece. Behringer B-2 Pro cardioid microphone and SSL AWS 948 console were used, while recording in Logic Pro X. After warming up, the performer played the first eight bars of the 1st movement: *Sarabande* from Sonata for Trumpet in Bb by J. Hubeau (Fig.1). Figures 1, 2 and 3 show the sounding pitch for each recording excerpt, as the trumpet was a transposing instrument. The notes contained in this excerpt were within the third and fourth octave.

Figure 1: Excerpt of Sarabande from Sonata for Trumpet in Bb by J. Hubeau.

The piece was recorded twice. For the first performance, the trumpet player adopted an optimal posture (with straight back and neck allowing for an unrestricted flow of air from the lungs to the lips). For the second performance, the head was rotated forward so that the flow of air was restricted by the different shape of the vocal tract. The analysis of the resonant frequencies was focused on segments of two bars duration (a musical phrase) and the comparison between the two postures is presented in Figs. 2 and 3.

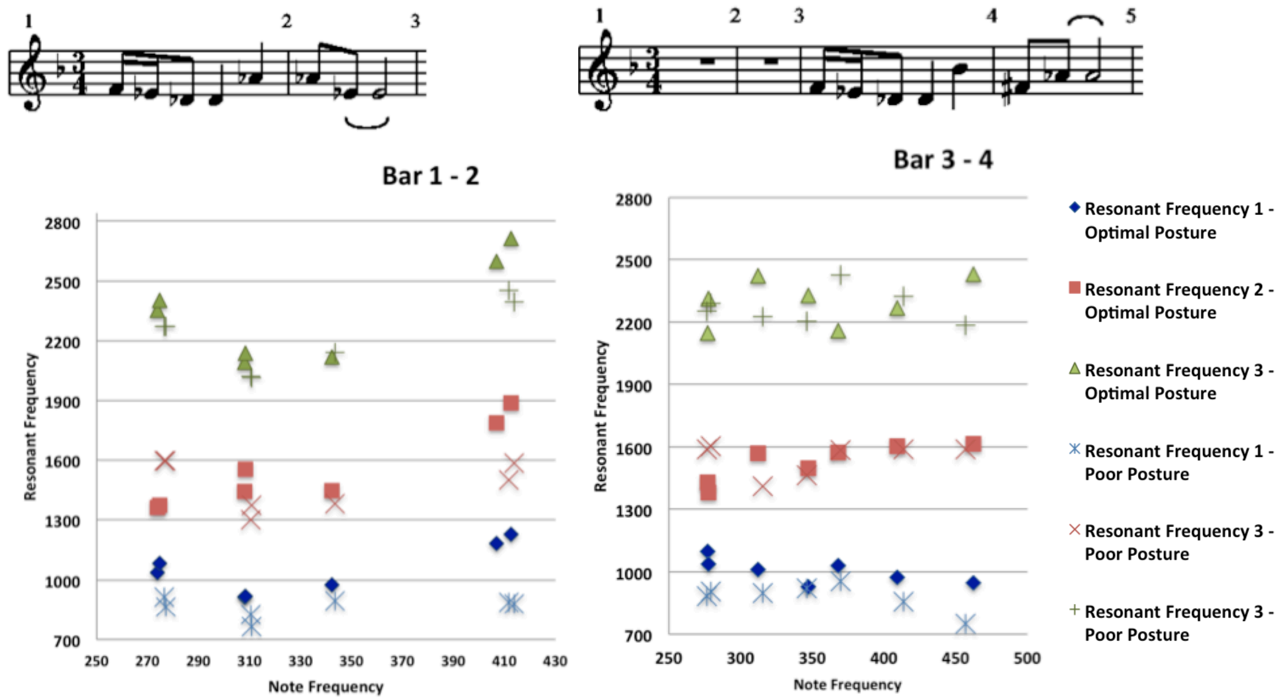


Figure 2: The first, second and third resonant frequencies plotted against the note frequencies for the excerpt of bar 1 and 2 (left) and excerpt of bar 3 and 4 (right). The plots show the analysis from both postures; optimal and poor.

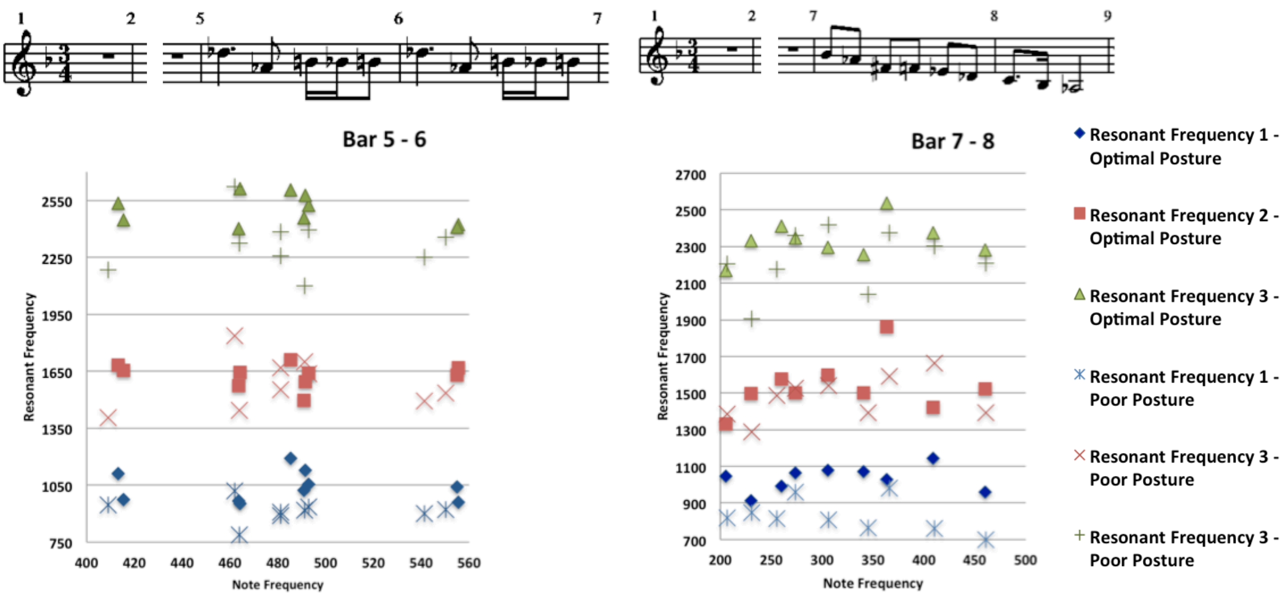


Figure 3: The first, second and third resonant frequencies plotted against the note frequencies for the excerpt of bar 5 and 6 (left) and excerpt of bar 7 and 8 (right). The plots show the analysis from both postures; optimal and poor.

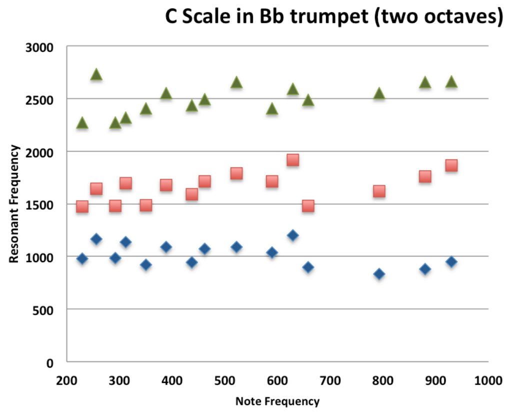
From the plots above, some interesting observations can be drawn. As Chen [18] suggested, the relationship between the note frequency and the resonant frequency is not consistent, as it has been observed for the clarinet and the saxophone ($f_{res}=f_o$). However, it is obvious that all three resonant frequencies tend to follow a particular pattern over a narrow frequency range. Specifically, the second resonant frequencies are between 1300-1600Hz (with few exceptions), while the third resonant frequencies lie between 2000-2500Hz. It is interesting that the deviation of the third resonant frequencies is not the same for all four excerpts. For example, at the third excerpt (bar 5-6), the range of the third resonant frequencies is from about 2400Hz to 2600Hz, when the posture is optimal.

It is also observed that the first resonant frequency produced with poor posture is lower (with one exception) than the corresponding first resonant frequency produced with optimal posture. It should be noted, however, that the note frequency has not been significantly affected by the poor posture, with an exception of the higher note of the piece being a Db (554Hz).

Another interesting point is that when the trumpet player performed the same note twice in each excerpt, the resonant frequencies were the same. This suggests that indeed those resonant frequencies are correlated with the produced note. Nevertheless, by comparing the first excerpt (bar 1-2) with the second excerpt (bar 3-4) there were four common notes (and their repeats), with different resonant frequencies for each excerpt. For example, the note Ab appears twice in the first excerpt, and the resonant frequencies remain the same for the repetition of both of the two different postures. Surprisingly, these frequencies have changed for the same note in the second excerpt for both postures, in the third excerpt (but similar with the repetition of the note there), and in the fourth excerpt as well. It is possible that this change was caused by the changing of the vocal tract shape or the position of the tongue. This shows that in order to investigate the final tone of the instrument, we need to consider how each of these factors affect the system.

2.2 Performing Scales and Arpeggios

The next step was to examine how these resonant frequencies change by performing the Bb scale and the arpeggio (a written C for the transposing instrument). The trumpet player was asked to play two octaves of the scale (upward) and the arpeggio (upward and downward), starting from Bb at the third octave. Figure 4 shows the results observed by analysing the resonant frequencies for both cases.



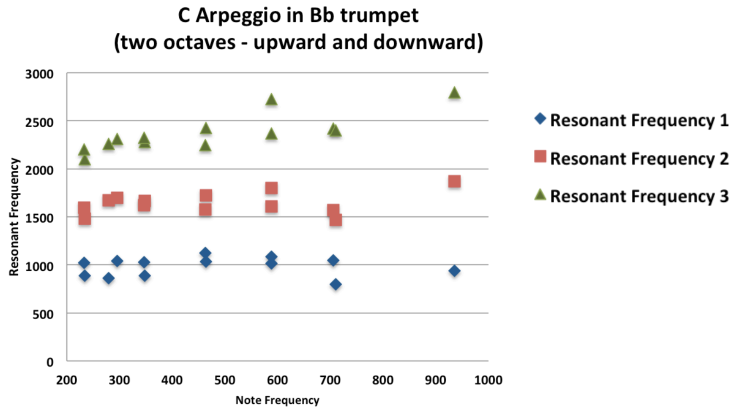


Figure 4: The first, second and third resonant frequencies plotted against the note frequencies for the C Scale (left) and the arpeggio (right).

From both plots, it can be seen that the three resonant frequencies are within a narrow frequency range. The first resonant frequency is between 880-1200Hz, the second is between 1450-1900Hz, and the third between 2000-2700Hz. This appears to be independent of the frequency of the note performed.

The results above, however, have been derived by studying one single trumpet player performing with the same trumpet and mouthpiece. Thus, the effect of a different mouthpiece was also investigated. In detail, a Yamaha 14A4A mouthpiece was used to perform the Bb scale and the arpeggio. This mouthpiece is shallower than the Yamaha TR-16C4-GP used in the previous example. Figure 5 shows the resonant frequencies of the scale (one octave - upward) and the arpeggio (two octaves - upward and downward).

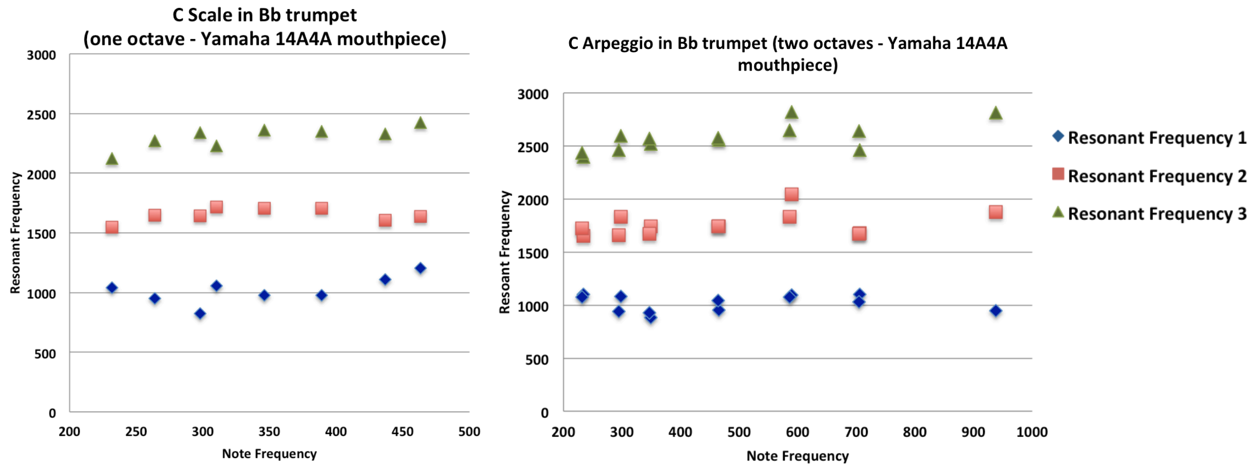


Figure 4: The first, second and third resonant frequencies plotted against the note frequencies for the C Scale (left) and the arpeggio (right). The mouthpiece used for these results was a Yamaha 14A4A.

The first resonant frequency is between 820-1200Hz, the second is between 1650-2000Hz, and the third between 2100-28500Hz. This seems to be independent of the frequency of the note performed or the octave band. By comparing these values with those observed with the Yamaha TR-16C4-GP mouthpiece, it is noted that the first resonant frequency remained within the same frequency range, while the second and third resonant frequencies have increased.

From the recordings of the scales and arpeggios with the two different mouthpieces, a slight increase of the second and third resonant frequencies, with increasing pitch, is observed at around 400Hz, while the first resonant frequency range remains the same. This has also been reported in [13] and [18], where it was argued that this can be explained if the tongue is positioned higher for higher pitch.

3. Conclusions

This study has confirmed the importance of the body posture of the trumpet player to the production of a consistent tone. It investigated how the performance of notes and their resonant frequencies are affected by changing the posture of the performer in a manner that restricted the vocal tract. For this case, one trumpet player performed music excerpts, scales and arpeggios using the same trumpet and mouthpiece. The recordings were then analysed and the resonant frequencies were presented. A constant pattern of resonant frequencies has been observed. Repetitive notes in the same musical phrase have the same resonant frequencies, but this may change depending upon its position within the melodic line. This could be assumed as a result of slightly different posture (include tongue, vocal tract or body position) for each new phrase.

The recordings of the scales and arpeggios were repeated with the same trumpet but using a different mouthpiece, in order to investigate its influence on the sound. It seems that the shallower cup of this different mouthpiece increased slightly the second and third resonant frequencies, while the first resonant frequency remained approximately within the same range. This will be the subject of further study in order to investigate the three resonant frequencies with different mouthpieces and different trumpet models and sizes, in order to check if they remain in the same frequency range. It should be also considered that those resonant frequencies may depend on the contribution of the individual player. Thus, the investigation will be expanded by recording and analysing the resonant frequencies of a larger sample of trumpet players.

REFERENCES

1 Arban, J. B. Arban's Complete Conservatory Method for Trumpet, Dover Books, New York, (2013).

2 Clarke, H. L. *Clarke's Technical Studies for the Cornet*, Carl Fischer Incorporated, New York, (1934).

3 Langey, O. Otto Langey's Practical Tutor for the Cornet Or Trumpet:Revised and Enlarged, Hawkes & Son, London, (1937).

4 Whitener, S. A complete guide to brass: Instruments and Pedagogy. Schirmer Books, New York, (1990).

5 Dornbusch, J. (1999) *Dental aspects in playing trumpet, trombone, horn, tuba and others*. [Online.} available: http://www.jazzer.de/bmd/homehalt.htm

6 Kelly, K. The dynamics of breathing: a medical/musical analysis with Arnold Jacobs and David Cugell MD, In *The Instrumentalist*, volume December 1983: 6-12, (1983).

7 Dalgleish, M. and Spencer, S. Postrum: Developing Good Posture in Trumpet Players through Directional Haptic Feedback, *Proceedings of the 9th Conference on Interdisciplinary Musicology - CIM14*, Berlin, Germany, (2014).

8 Dalgleish, M., Payne, C. and Spencer, S. Postrum II: A Posture Aid for Trumpet Players, Proceedings of the 2015 *Linux Audio Conference (LAC15)*, Mainz, Germany, (2015)

9 Vaseghi, S. V., *Multimedia Signal Processing*, John Wiley & Sons, West Sussex, England, (2007).

10 Benade, A. H. Interactions between the player's windway and the air column of a musical instrument, *Cleve Clin Q*, **53**, 27-32, (1986).

11 Wolfe, J., Fletcher, N. H., and Smith, J. The interactions between wind instruments and their players, *Acta Acustica United with Acustica*, **101**, 211-223, (2015).

12 Tarnopolskly, A., Fletcher, N. H., Hollenberg, L. C. L., Lande, B. D., Smith, J., and Wolfe, J. *The vocal tract and the sound of the didgeridoo*, Nature, London, **436**, 39, (2005).

13 Fritz, C., and Wolfe, J. How do clarinet players adjust the resonances of their vocal tracts for different playing effects?, *Journal of the Acoustical Society of America*, **118**, 3306-3315, (2005).

14 Wilson, T. D. The measured upstream impedance for clarinet performance and its role in sound production, Ph. D. Thesis, University of Washington, Seattle, WA, (1996).

15 Chen, J.-M., Smith, J., and Wolfe, J. Pitch bending and glissandi on the clarinet: roles of the vocal tract and partial tone hole closure, *Journal of the Acoustical Society of America*, **126**, 1511-1520, (2009).

16 Scavone, G. P., Lefebre, A., and Da Silva, A. R. Measurement of vocal-tract influence during saxophone performance, *Journal of the Acoustical Society of America*, **123**, 2391-2400, (2008).

17 Chen, J.-M., Smith, J., and Wolfe, J. Experienced saxophonists learn to tune their vocal tracts, *Science*, **319**, 726, (2008).

18 Chen, J.-M., Smith, J., and Wolfe, Do trumpet players tune resonances of the vocal tract? *Journal of the Acoustical Society of America*, **131**, 722-727, (2012).